Surface Wear

Analysis, Treatment, and Prevention

R. Chattopadhyay

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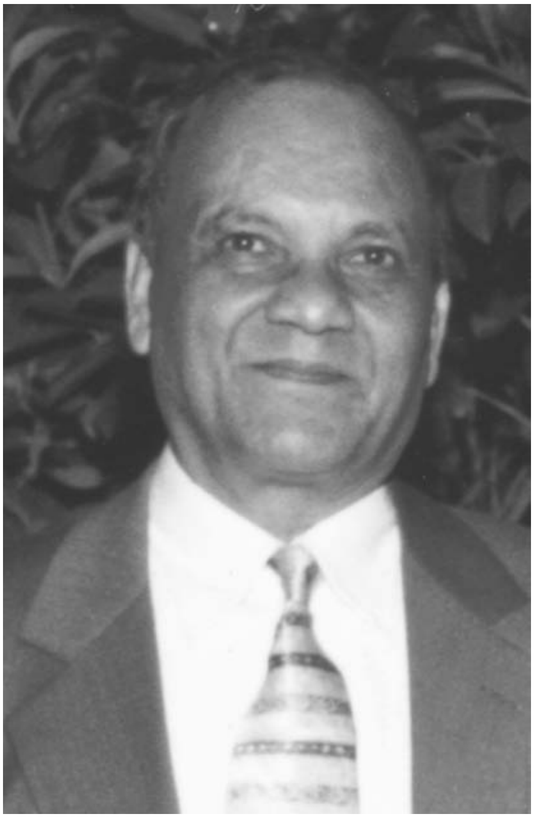
Cover illustration *shows extensive wear damage occurring in a Pelton Wheel-type turbine after only one year in operation. All hydroturbines (including Francis and Kaplan-type turbines) in operation in northern India, Bhutan, Nepal, and some parts of China and Russia were likely to sustain this type of damage. Such extensive wear was caused by high silt content in the river waters precipitated by heavy deforestation in these areas. Due to the hostile wear environments, turbine materials used in these areas did not last for more than a fraction of their designed life. It took several years of extensive laboratory and field studies before the author was able to find a viable solution to minimize wear under such hostile environmental conditions.*

About the Author

Dr. R. Chattopadhyay won a B.S. (honors) and Ph.D. in metallurgical engineering from the University of London. He is a fellow of the Institute of Materials (U.K.), chartered engineer (Engineering Council, U.K.), member of ASM International and the American Welding Society, and a life member of Indian professional bodies on metal, welding, powder metallurgy, and tribology. He has served as a member of various high-level committees formed by the government of India and her agencies on concurrent subjects such as advanced materials and processes, catalytic converter, titanium development, and many others. He has been an examiner for master and doctoral theses from Indian Institute of Technology and Bombay University.

His long research career spanning over 3.5 decades started at Boliden Gruvaktiebolg, Sweden, where he worked as a student trainee on the mechanism of ambient temperature sintered mass formation of fine pyrite ore. Dr. Chattopadhyay has worked as a trainee in a fabrication workshop in Germany.

In India he has worked for National Metallurgical Laboratory (NML), Tube Investment of India (subsidiary of TI, U.K.), a subsidiary of Larsen and Toubro Ltd., and several other organizations. Some highlights of his research contributions include pioneering research on the development of microalloyed high-strength, low-alloy (HSLA) steels and the key role played in producing successfully the very first commercial heats and subsequent controlled rolling of HSLA steels in India, doing the complete failure analysis based on which the first-ever product liability (fitness for the purpose) case in India was won, and finally, setting up a unique wear control research center catering to the needs of almost all the major industries. A wide range of critical wear problems associated with applications such as railroad frogs, hydro and steam turbines (power), gas turbine (power and aeroengine), submarine tubes, Nimonic bar forging hammer (steel), Osepa separator (cement), engine valves (automotive) and process control valves (chemical and petrochemical), tricone bits (mining), wear rings, and many others were successfully solved through sustained laboratory wear studies and development of advanced products, techniques, procedures, and finally, trials in the laboratory and in the field. Dr. Chattopadhyay has visited a large number of industries, research centers, and academic institutions; attended national and international conferences across the world; and presented papers on welding, thermal spraying, wear, powder metallurgy, and advanced materials. He has published approximately 100 research and technical papers. Recently he was awarded the Jindal gold medal by the Indian Institute of Metals in recognition of his outstanding contribution in his area of work.



To the memory of
Jatindra Mohan Chatterjee,
my father

ASM International Technical Books Committee (2000–2001)

Preface

While setting up a unique research laboratory on wear control, and subsequently working as a head of the research and development unit, I had the opportunity to interact with engineers from a wide range of industries—including automotive, railway, power plant, iron and steel, cement, mining, aerospace, petrochemical, and chemical. The engineers mostly rely on coating producers and suppliers for solutions to the wear problems of their respective industries. Quite often, they are (mis)guided by either the earlier precedent from similar applications at other facilities, which may not work for their application due to the changed wear environment; or by the specific benefits provided by coating producers and/or suppliers for a particular process or material, information that often does not mention any of the pitfalls.

Modern equipment is highly sophisticated, mostly automated, and expensive. This equipment is designed to sustain high production rates for a reasonable period. Advanced materials and surface engineering processes are used in manufacturing the equipment in order to minimize wear. However, reconditioning by appropriate systems/materials during maintenance provides an opportunity to extend the life of the equipment beyond the stipulations made in the original design. In order to provide viable solutions to the critical wear problems of modern equipment, either at the design or reconditioning stage, specialized knowledge in the area of wear prognosis is essential.

The bow and arrow makers of yesteryear, however well paid and willing, could not design, operate, or maintain a rocket launcher.

The process of solving critical wear problems requires extensive interactions with engineers working at different levels in the industry. Additionally, I have conducted a large number of short courses, workshops, and seminars on various aspects of wear control technology, including a semester duration course for undergraduate metallurgical engineering students at Indian Institute of Technology, Mumbai. While conducting the courses or working on wear problems in industries, I came across a large cross section of engineers at all levels, who felt the need for a book on wear prognosis technology, preferably authored by an experienced professional from the industry. Wear prognosis basically consists of diagnosing the cause of wear and then prescribing an appropriate solution to minimize wear. A book on this subject is expected to provide proper understanding of the surface properties controlling the wear processes in different environments and the techniques to reduce specific type of wear through modification of surface properties. I hope and believe that this book addresses these and other queries pertaining to wear prognosis.

I gratefully acknowledge the support and encouragement that I have received from various sources during the preparation of this manuscript.

I appreciate the support and encouragement that I have received from my elder son, Dr. Romik Chatterjee, of the University of Texas at Austin, and his wife, Robin Pearson. My younger son, Raunak Chatterjee, M.S. (UT, Austin), has been a constant source of inspiration.

Further, I wish to thank various authors and publishers for permitting the use of their data and diagrams in this book. Thanks are due also to the staff members of ASM International who have made printing this book possible. A word of appreciation goes to Veronica Flint of ASM International for her unending support and guidance in this project. I would like to convey my sincere thanks to Carol Terman for her gallant efforts in successfully completing the project.

This acknowledgment would not be complete without a word of thanks to my wife, Dr. Mandira Chatterjee, for her unfailing support throughout this undertaking.

Contents

Introduction

During the last two decades the concept of "engineering" the surface so as to afford protection against environmental degradation has gained importance as part of an effort to conserve natural resources. The engineered surface extends the working life of components in hostile environments for both original equipment manufacturer (OEM) and recycled parts. The extension in working life and the process of recycling through reconditioning lead to conservation of material and energy.

Modern equipment and machinery are far more expensive and are designed to work in more hostile environments than their predecessors were (e.g., Intercontinental Ballistic Missile and supersonic jet engine components compared with earlier guns and airplanes). It is imperative, therefore, that the components are protected against environmental degradation in order to ensure satisfactory and reliable performance over a prolonged working life for both engineered and re-engineered surfaces.

The tribological interaction of the bounding face or surface of a component with the environment can result in loss of material from the surface. The process that results in the loss of material due to interaction with the environment is known as *wear*. The characteristic properties of the surface (e.g., surface energy, roughness, microstructure and macrostructure, and composition) play an important part in the wear process. The working environment can cause different types of wear to the components of equipment and machines. The various types of wear can be broadly classified in five major types—abrasion, adhesion, thermal, erosion, and corrosion. The effect of the stress field on the wear rate depends on the stress vector (i.e., both on magnitude and direction). The mechanism of material removal from the surface has been explained in terms of cutting, plowing, delamination, pitting, cavitation, and so on, and/or fatigue. The mechanism of wear in metals and ceramics is similar to but significantly different from that of plastic.

A wide variety of materials and processes are available to prevent loss due to wear. These include improvement of the wear-resistant properties of the surface through work hardening; selective heat treatment (e.g., induction or flame or laser hardening); diffusing in interstitials or substitutionals (C, N, Al, Cr, Zn); conversion coating (P, Cr); thin film coatings such as electroplating, electroless plating, chemical vapor deposition (CVD), physical vapor deposition (PVD), sol-gel process; and thick film coating by welding and thermal spraying.

Metal, ceramic, or plastic surfaces can be protected against wear either through surface modification or through deposition of wear-resistant materials. The wear-resistant overlay materials can be metal, ceramic, plastic, or composite.

It is necessary to identify the predominant type of wear process(es) in order to decide on an appropriate technology for modifying the surface to minimize the wear. The multidisciplinary approach to diagnose wear mode and to prescribe a solution to the wear problem can be most appropriately termed as *surface wear prognosis technology.*

A recent survey indicates loss due to wear at $200 billion in the United States per year. In this book, an attempt is made to cover various aspects of wear prognosis technology—a proper understanding of which will result in enormous savings to industry by reducing loss due to wear, while at the same time ensuring the preservation of resources in terms of material, energy, and the environment.

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Surface wear damage is a phenomenon which effects how a component will last in service. An example of a component working in an aggressive environment is a cutting tool used in machining processes. The tool experiences high loads, high speeds and friction and, as a consequence, high temperatures: These factors lead to surface wear of the component. Lubrication in